OVERVIEW OF ASYMMETRIC DM.

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OUTLINE.

- MOTIVATION & FUNDAMENTALS
- GENESIS:
  - SHARING.
  - COGENESIS
  - MISC
- RELIC DENSITY
- PHENOMENOLOGICAL ASPECTS

REFERENCES.

REVIEW: ZUREK 1308.0338

EARLY PAPERS: NUSSINOV 1985 (HEAVY)

GELMINI, HALL, JIN 1987
KAPLAN, LUTY, ZUREK 0901.4117 } (LIGHT)

RELIC DENSITY:

OVERVIEW of ADM

Zurek. 1308.0338.

→ KNOWN STABILISING SYMMETRIES spin, B - global $U(1)$, $e^{\pm}$

ν p e

→ ADM: REUSE KNOWN MECHANISM NEW (APPROX) $U(1)$ GLOBAL

DARK MATTER STABILISED BY (APPROX) CONSERVED GLOBAL Q etc

→ ONE STEP FURTHER: ASYMMETRY $n_X - n_{\bar{X}}$ SETS RELIC DENSITY

IN SM $\frac{n_B - n_{\bar{B}}}{s} \sim 10^{-10}$ $\left(s \propto T^3\right)$

$n_{\bar{B}}\big|_{today} \sim 10^{-10^5}$.

→ FINAL STEP IN LOGIC: IS TO CONNECT X AND B ASYMMETRIES

THIS IS MOTIVATED IN SM SPHALERONS SHARE ASY —

→ THEN RELIC DENSITIES RELATED ($\Omega_{DM} \sim \Omega_B$)

$$\frac{\Omega_{DM}}{\Omega_B} \sim \frac{M_X \eta_{DM}}{M_p \eta_B}$$

→ OBSERVATION: $\frac{\Omega_{DM}}{\Omega_B} \sim 5$ IF $\frac{\eta_{DM}}{\eta_B} \sim 1 \Rightarrow M_X \sim M_p$.

OR CONVERSELY $\frac{\eta_{DM}}{\eta_B} \neq 1$, $\frac{M_X}{M_p} \sim 1$ EXPLAINS $\Omega_{DM} \sim 5\,\Omega_B$

→ REDUCES A MYSTERIOUS COINCIDENCE TO TRACTABLE COINCIDENCE.

→ WIMP SCENARIO NOT WELL UNDER STOOD

Ω_B ~ CP odd PHYSICS

Ω_{DM} ~ CP even PHYSICS (F.O).

LIKELY THESE CONNECTED (BOTH CP odd)

→ ALSO OF INTEREST $M_X \sim M_p \Rightarrow$ LIGHT DM (ANOMALIES)

GELMINI, HALL, JIN 1987

KAPLAN, LUTY, ZUREK 0901.4117.

OVERVIEW ADM

c. REALISATION: DM CARRIES GLOBAL Q # X ASSOCIATED TO $U(1)_X$

→ ALL INDIVIDUAL Q # BROKEN ONLY LIN COMB PRESERVED

eg $U(1)_{B-L+X}$ BUT B, L, X GOOD APPROX.

→ SHARING/GENESIS BREAK LATTER BUT PRESERVE FORMER
TIE IN.

3. (AFTER LIGHT MASS SCALE)

HEAVY REGIME ADM

MOTIVATION TECHNICOLOR NUSSINOV 1985.

NOTE

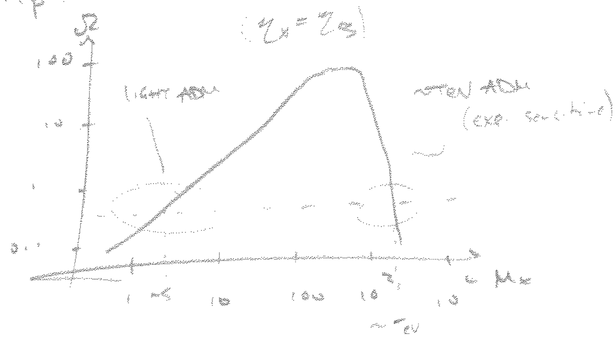
∴ $M_X \gg T$ $\quad n_X \simeq n_\gamma e^{-(M_X-\mu)/T}$ $\quad (n_{\bar X} \sim \mu \to -\mu)$

FOR $M_P \ll T$ THEN $n_B = n_\gamma e^{\mu/T}$

$$\Rightarrow \frac{\Omega_{DM}}{\Omega_B} = \frac{n_X - n_{\bar X}}{n_B - n_{\bar B}} \cdot \frac{M_X}{M_P} \simeq \frac{M_X}{M_P} e^{-M_X/T} \quad (\eta_X = \eta_B)$$

RELIES ON $M_P \ll T \ll M_X$

FOR BOLTZMANN SUPPRESSION



COMMENTS ON MASS

A. FUND. PROBLEM:

- Λ SCALE - ORIGIN OF EWSB — FRANDSEN SARKAR DESY. PRES. 2010. 03.

  $\frac{\Lambda}{16\pi^2} \sim M_{ADM} \sim GeV$ — COHEN 1005.1655 (ET AL), MORRISSEY 0904.2567.

- DYNAMICS IN HIDDEN SECTOR MIRRORS SM $\Lambda_{ADM} \sim \Lambda_{QCD}$

- LINKED TO VEV CAUSES P.T. → X GENESIS

↑ READ

TeV ADM → TECHNICOLOR / COMPOSITE HIGGS

ADM GENESIS: SHARING.

VARIOUS SCENARIOS.

SHARING $B,L \to X$ (B-L GENESIS) $X \to B,L$ (XOGENESIS) $X \to L \to B$ (XOGENESIS THEN SPHALERONS)

COGENESIS B,X COGEN B,L COGEN $\xrightarrow{\text{sphalerons}} B$.

SHARING BETWEEN HIDDEN/VISIBLE SECTOR 2 WAYS.

- (GENERALISED) SPHALERONS
- EXPLICIT $\not{X}$ OPERATORS.

- TO SHARE VIA EW SPHALERONS REQUIRES.
  - HIDDEN SECTOR STATE (DM?) CARRYING X /W $SU(2)_W$ CHIRAL ANOMALY.

$$\partial_\mu j^\mu = \frac{N g^2}{64\pi^2} \varepsilon^{\mu\nu\rho\sigma} F^a_{\mu\nu} F^a_{\rho\sigma} \neq 0$$

DIVERGENCE OF B, L, X.

FOR N $SU(2)$ DOUBLETS.

$$\partial_\mu j^\mu \propto tr\left(\tau^a \tau^b X\right) = \frac{1}{2}\delta^{ab} \sum_i X_i$$

FOR X_i $U(1)_X$ CHARGE OF STATES TRANSFORMING UNDER $SU(2)_W$.

- FOR $\partial_\mu j^\mu \neq 0 \Rightarrow X$ VIOLATED BY EW. SPHALERONS.

- LIGHT ~10 GeV DM PARTICIPATING IN SPHALERONS: LIMITS INV. Z. ALSO EW PRECISION TESTS
- ~TeV ADM /W SPHALERONS - OK BARR '91
- ~TeV HIDDEN SECTOR STATES CHARGED UNDER $U(1)_X$ & $SU(2)_W$ BUT NOT DM. SUBSEQU. DECAY TO DM /W $U(1)_X$ BUT SM SINGLET.
- LARGER GROUP (NOT $SU(2)_W$) THAT B, L, X ALL CHARGED UNDER - NEW SPHALERONS i.e. UNDER WHICH BOTH X AND B AND OR L ARE ANOMALOUS. FRANDSEN ET AL 1103.4350.

BLENNOW ET AL 1009.3159

- nb ASYMMETRY MAY ACTUALLY BE GENERATED BY PHASE TR. BREAKING NEW GROUP. AS IN EW BARYOGENESIS.

EXAMPLES. DUTTA/KUMAR 0608188 1012.1341

SHARING VIA HIGH DIM OPERATOR

- OF THE FORM $\boxed{M^{-n} \mathcal{O}_{DM} \mathcal{O}_{VIS}}$ ~~E~~ SIMPLE CHOICE $\mathcal{O}_{DM} = X$.

$\mathcal{O}_{VIS} = u^c d^c d^c,\ q L d^c,\ L L e^c,\ L H$ OR RPV OPERATOR OF SUSY

OPERATORS CAN SHARE ASYM. BETWEEN SECTORS. SHELTON 1008.1997

BUT CAN ALSO WASHOUT ASYM.

→ REQUIRE ~~[illegible]~~ BOLTZMANN ANALYSIS (OR SIMILAR)

CAN BE CALCULATED IN TERMS OF RELATIVE Γ HARVEY, TURNER 1990.

~~EXAMPLE FROM 1308.0338~~ SPECIFIC REALISATIONS. KAPLAN, LUTY ZUREK. 0901.4117

~~$\mathcal{O}_{B-L}$ CARRIES B-L # AS OPERATOR DECOUPLES~~

~~ABOVE EWPT ALL SM, DM STATE IN TE $\frac{79}{22} \frac{|\eta|}{\Omega}$ ... BELOW EWPT t, H OUT OF EQ. $\frac{79}{22} \to \frac{9}{2}$~~

$\boxed{X_0 \text{ GENESIS}}$

SHARING ASSUMES PRIMORDIAL ASYMMETRY

- THIS IS TYPICALLY OK AS ASYM CAN BE ESTABLISHED VIA BM - GENESIS OR X_0 GENESIS

X_0 GENESIS OCCURS IF HIDDEN SECTOR SATISFIES SAKHAROV

EXAMPLES:
- DARK "ELECTROWEAK" BARYOGENESIS ⊗ eg. CHEUNG & ZHANG 1306.4321 SHELTON 1008.1997
- ~~DARK~~ SPONTANEOUS DARK/CO GENESIS COHEN et al. 9406345
- DARK "LEPTOGENESIS" JMR & MCCULLOUGH 1106.4319

eg. 1101.4936. FALKOWSKI et al.

1308.0330: INTERESTING QUESTION: WHAT IS MINIMAL MODEL FOR ⊗.

- BASIC REQ: GLOBAL $U(1)_X$ ANOMALOUS UNDER $SU(N)$ ARE DIFFERENT FOR SUSY non-SUSY?

• REF PROPOSES: $\mathcal{L} = -\frac{m^2 H^2}{2} + \frac{\lambda}{4} H^4 + y_i L H X_i$ $i = 1,2$

	$SU(N)$	$U(1)_X$
H	□	1
L	□	0
X	1	1

L, H, X ALL HIDDEN SECTOR, ~~[illegible]~~ REPR:

NB HIERARCHY PROBLEM POTENTIALLY

H BREAKS $SU(N)$ → PARAMETERS FREE SO CAN BE 1^{st} ORDER → STILL GIVES GRAVITY WAVE!

$\langle H \rangle$ GIVES DM MASS SO SHOULD BE ~ GeV.

ADM: Cogenesis

EXAMPLES:

- DECAY MODELS. – OUT-OF-EQ DECAYS TO X AND SOMETHING CARRYING B & L

(OR SIMILAR) (*)

SEE E.G. FALKOWSKI 1101.4936

- AFFLECK-DINE – FLAT DIRECTION CARRYING B-L AND $\cancel{B}$X SIMULTANEOUSLY

GENERATES BOTH SYMMETRIES. REF. CHEUNG 1105.4612

- "ELECTROWEAK BARYOGENESIS" WITH HIDDEN SECTOR CHARGED UNDER SU(2)$_H$

(*) → MINIMAL EX

- GRAVITATIONAL

- INFLATIONARY – LACKING?

FINAL NOTES:

PROMINENT Q'S:

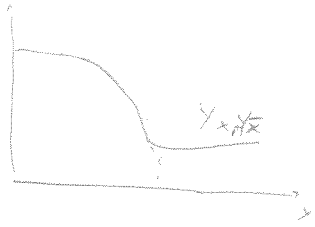
- WHY $M_X \sim$ GeV ?
- MINIMAL MODELS FOR H.S. 1ST ORDER P.T.
- NEW SCENARIOS FOR DARKOGENESIS?
  → INFLATIONARY COGENESIS

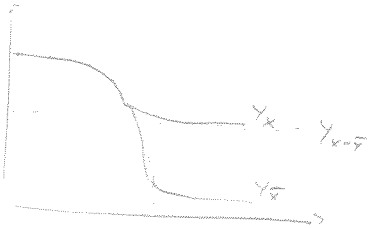
*DM : Relic Density

Not sufficient to generate an asymmetry.

Asymmetry is $O(\epsilon)$ down from thermal DM densities for $T > M_{DM}$

$$Y_{X\bar{X}} \sim \epsilon\, Y_{X+\bar{X}}$$





Before $T < M_{DM}$

$Y_{X,\bar{X}}$ [Boltzman suppressed]

Require [annihilations not ϵ-0] before $Y_{X-\bar{X}} \gg Y_{X+\bar{X}}$

Note form of yields $\Rightarrow$

$$Y_X = \frac{\eta_X}{1 - e^{-\eta_X\left(\frac{s}{x_f} + \frac{3b}{x_f}\right)}} \; ; \; Y_{\bar{X}} = \frac{\eta_X}{e^{-\eta_X\left(\frac{s}{x_c} + \frac{3b}{x_f}\right)}}$$

For $\langle\sigma v\rangle \sim a + \frac{6b}{x}$ with $M_X M_{Pl}\sqrt{g_*}$

1104.5548.

Require [large couplings] of DM to remove symmetric component.

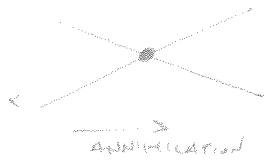
Minimal manner is to couple directly to SM states via effective O_P $\Rightarrow$ only new light DoF is DM.

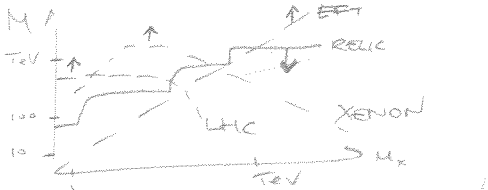
e.g. $\frac{M_2}{M^2} X^2 \bar{q} q$.

Efficient annihilation $\Rightarrow$ M relatively small

DM [complementarity] implies.

1203.4854





Use LHC + DD to constrain minimum size of M.

$\Rightarrow$ either [light mediators] to avoid LHC constraints (resonances) and S-D or momentum [suppressed DD] cross-sections

OK. annihilation to light hidden sector states

But in this case [DM-DM scattering] (Bounds)

Zurek 1111.0293 etc.

Other points of interest:

- Neutron star collapse & Bosonic ADM
- Deviation in stellar processes.
- Minimal model $\Rightarrow$ no annihilation (cf. see eg. 1402.4500)

ab. light mass cases for G.C. excess.